WHAT IS CLAIMED IS:

1. In a digital communication system, a method for communicating comprising the steps of:

transmitting signals from one or more transmitter antenna elements;

receiving said signals from via a plurality of receiver antenna elements;

wherein separation of radiation patterns among either said transmitter antenna elements or said receiver antenna elements is insufficient to establish completely isolated spatial directions for communication; and wherein

at least one of said transmitting and receiving steps comprises processing said signals to increase isolation between spatial directions employed for communication at a common frequency.

2. The method of claim 1 wherein a channel coupling said plurality of transmitter antenna elements and receiver antenna elements at said common frequency is characterized by a spatial channel matrix having a rank greater than one.

3. In a digital communication system, a method for communicating comprising the steps of:

transmitting signals from one or more transmitter antenna elements;

receiving said signals via a plurality of receiver antenna elements;

wherein separation of radiation patterns among either said transmitter antenna elements or said receiver antenna elements is insufficient to establish completely isolated spatial directions for communication; and wherein

at least one of said transmitting and receiving steps comprises processing said signals to increase isolation between subchannels, each subchannel associated with a spatial direction and a bin of a substantially orthogonalizing procedure.

4. The method of claim 3 wherein said substantially orthogonalizing procedure belongs to a group including: an inverse Fast Fourier Transform, a Fast Fourier Transform, a Hilbert transform, a wavelet transform, and processing through a set of bandpass filter/frequency upconverter pairs operating at spaced apart frequencies..

5.   In a digital communication system, a method for preparing a sequence of symbols for transmission via a plurality of inputs of a channel:

a) inputting said symbols of said sequence into a plurality of inputs corresponding to a plurality of subchannels of said channel, each subchannel corresponding to an input bin of a transmitter substantially orthogonalizing procedure and a spatial direction;

b) for each input bin, spatially processing symbols inputted to said subchannels corresponding to said input bin, to develop a spatially processed symbol to assign to each combination of channel input and input bin of said transmitter substantially orthogonalizing procedure; and

c) applying, independently for each said channel input, said transmitter substantially orthogonalizing procedure to said spatially processed symbols assigned to each said channel input.

6.   The method of claim 5 wherein said b) step has the effect of making spatial directions of said subchannels into a set of orthogonal spatial dimensions.

7.   The method of claim 5 wherein said transmitter substantially orthogonalizing procedure belongs to one of a group consisting of an inverse Fast Fourier Transform, a Fast Fourier Transform, a discrete cosine transform, a Hilbert transform, a wavelet transform, and processing through a plurality of bandpass filter/frequency converter pairs centered at spaced apart frequencies.

8.   The method of claim 5 further comprising the step of, after said c) step, applying a cyclic prefix processing procedure to a result of said substantially orthogonalizing procedure independently for each channel input.

9.   The method of claim 5 wherein said transmitter substantially orthogonalizing procedure is optimized to reduce interference to unintended receivers.

62   10.   The method of claim 5 wherein said b) step comprises, for each

63   particular input bin, multiplying a vector comprising symbols allocated to subchannels

64   corresponding to said input bin by a beneficial weighting matrix, elements of a result vector of

65   said multiplying step corresponding to different channel inputs of said plurality of channel

66   inputs.

67

68   11.   The method of claim 10 wherein said beneficial weighting matrix

69   comprises an input singular matrix of a matrix containing values representing characteristics of

70   said channel, said coupling said plurality of channel inputs to one or more channel outputs.

71

72   12.   The method of claim 10 wherein said beneficial weighting matrix is

73   obtained from a matrix containing values representing characteristics of a channel coupling

74   said plurality of channel inputs to one or more channel outputs.

75

76   13.   The method of claim 10 wherein said beneficial weighting matrix is

77   chosen to reduce interference to unintended receivers.

78

79   14.   The method of claim 13 wherein said beneficial weighting matrix is

80   chosen based upon characterization of a desired signal subspace.

81

82   15.   The method of claim 14 wherein said beneficial weighting matrix is

83   chosen further based upon characterization of an undesired signal subspace.

84

85   16.   The method of claim 15 wherein characterizations of said desired signal

86   subspace and said undesired signal subspace are averaged over at least one of time and

87   frequency.

88

89   17.   The method of claim 10 wherein said b) step comprises performing said

90   spatial processing step so as to reduce interference radiated to unintended receivers.

91   18.   The method of claim 10 wherein said b) step comprises, for each input

92   bin, allocating symbols to each combination of channel input and input bin so that there

93   is a one-to-one mapping between spatial direction of a particular subchannel to which a

94   particular symbol has been allocated and channel input to which said particular symbol

95   is allocated.

96

97   19.   The method of claim 10 further comprising the step of prior to said b)

98   step applying a coding procedure to said symbols.

99

100   20.   The method of claim 19 wherein said coding procedure is applied

101   independently for each of said subchannels.

102

103   21.   The method of claim 19 wherein said coding procedure is applied

104   independently for each group of subchannels corresponding to an input bin of said substantially

105   orthogonalizing procedure.

106

107   22.   The method of claim 19 wherein said coding procedure is applied

108   independently for each group of subchannels corresponding to a particular spatial direction.

109

110   23.   The method of claim 19 wherein said coding procedure is applied

111   integrally across all of said subchannels.

112

113   24.   The method of claim 19 wherein said coding procedure belongs to a

114   group consisting of: convolutional coding, Reed-Solomon coding, CRC coding, block coding,

115   trellis coding, turbo coding, and interleaving.

116

117   25.   The method of claim 19 wherein said coding procedure comprises a

118   trellis coding procedure.

119

120   26.   The method of claim 25 wherein a code design of said trellis coding

121   procedure is based on one of: improved bit error performance in interference channels, a

122   periodic product distance metric, exhaustive code polynomial search for favorable bit error

123   rate polynomial searches, combined weighting of product distance and Euclidean distance,

124   product distance of multiple Euclidean distances over short code segments or over a multi-
125   dimensional symbol, and sum of product distances over short code segments.
126

127   27.   The method of claim 25 wherein a code design of said trellis coding
128   procedure is optimized for performance in a fading matrix channel.
129

130   28.   The method of claim 19 wherein said coding procedure comprises a one-
131   dimensional trellis coding procedure followed by an interleaving procedure with sequential
132   groups of symbols output by said trellis coding having their internal order maintained by said
133   interleaving procedure.
134

135   29.   The method of claim 19 wherein said coding procedure comprises a
136   multi-dimensional trellis coding procedure followed by an interleaving procedure with groups
137   of one-dimensional symbols output simultaneously by said multi-dimensional trellis coding
138   procedure having their internal order maintained by said interleaving procedure.
139

140   30.   The method of claim 10 wherein bit loading and power are allocated to
141   each subchannel.
142

143   31.   The method of claim 10 further comprising the step of retransmitting
144   symbols by repeating at least one of said a), b), and c) steps upon receipt of a notification that
145   said symbols to be retransmitted have been incorrectly received.
146

147   32.   The method of claim 10 wherein said channel comprises a wireless
148   channel and said plurality of channel inputs are associated with a corresponding plurality of
149   transmitter antenna elements
150

151   33.   The method of claim 32 wherein said plurality of transmitter antenna
152   elements are co-located.
153

154   34.   The method of claim 32 wherein said plurality of transmitters are at

155 disparate locations.

156

157   35.   A method of processing a sequence of symbols received via a plurality of

158 outputs of a channel, said method comprising the steps of:

159   a) applying a receiver substantially orthogonalizing procedure to said sequence

160 of symbols, said procedure being applied independently for each of said plurality of channel

161 outputs, each output symbol of said receiver substantially orthogonalizing procedure

162 corresponding to a particular output bin and a particular one of said channel outputs; and

163   b) for each output bin, spatially processing symbols corresponding to said

164 output bin to develop spatially processed symbols assigned to a plurality of spatial directions,

165 each combination of spatial direction and output bin specifying one of a plurality of

166 subchannels.

167

168   36.   The method of claim 35 wherein said b) step has the effect of making

169 said plurality of spatial directions into a set of orthogonal spatial dimensions.

170

171   37.   The method of claim 35 wherein said receiver substantially

172 orthogonalizing procedure belongs to one of a group consisting of an inverse Fast Fourier

173 Transform, a Fast Fourier Transform, a discrete cosine transform, a Hilbert transform, a

174 wavelet transform, and processing through a plurality of bandpass filter/frequency converter

175 pairs centered at spaced apart frequencies.

176

177   38.   The method of claim 35 further comprising the step of, prior to said a)

178 step, applying a cyclic prefix removal procedure to said sequence of symbols independently

179 for each of said channel outputs.

180

181   39.   The method of claim 35 wherein said receiver substantially

182 orthogonalizing procedure is optimized to reduce deleterious effects of interference from

183 undesired co-channel transmitters.

184

185   40.   The method of claim 35 wherein said b) step comprises, for each

186 particular output bin, multiplying a vector comprising symbols of said output bin by a

187 beneficial weighting matrix, elements of a result vector of said multiplying step corresponding

188 to different spatial directions.

189

190   41.   The method of claim 40 wherein said beneficial weighting matrix

191 comprises an output singular vector of a matrix containing values representing characteristics

192 of said channel, said channel coupling one or more channel inputs to said plurality of channel

193 outputs.

194

195   42.   The method of claim 40 wherein said beneficial weighting matrix is

196 chosen to minimize deleterious effects of interference from undesired transmitters.

197

198   43.   The method of claim 42 wherein said beneficial weighting matrix is

199 chosen based upon characterization of a desired signal subspace.

200

201   44.   The method of claim 43 wherein said beneficial weighting matrix is

202 chosen further based upon characterization of an undesired signal subspace.

203

204   45.   The method of claim 44 wherein said characterizations of said desired

205 signal subspace and said undesired signal subspace are averaged over at least one of time and

206 frequency.

207

208   46.   The method of claim 40 wherein said beneficial weighting matrix is

209 obtained from a matrix containing values representing characteristics of said channel, said

210 channel coupling one or more channel inputs and said plurality of channel outputs.

211

212   47.   The method of claim 46 wherein said beneficial weighting matrix is

213 obtained by an MMSE procedure.

214

215   48.   The method of claim 35 further comprising the step of after said b) step

216   applying a decoding procedure to said symbols.

217

218   49.   The method of claim 48 wherein said decoding procedure is applied

219   independently for each of said plurality of subchannels.

220

221   50.   The method of claim 48 wherein said decoding procedure is applied

222   independently for each group of subchannels corresponding to an output bin of said

223   substantially orthogonalizing procedure.

224

225   51.   The method of claim 48 wherein said decoding procedure is applied

226   independently for each group of subchannels corresponding to a spatial direction.

227

228   52.   The method of claim 48 wherein said decoding procedure is applied

229   integrally across all of said plurality of subchannels.

230

231   53.   The method of claim 48 wherein said decoding procedure belongs to a

232   group consisting of: Reed-Solomon decoding, CRC decoding, block decoding, and de-

233   interleaving.

234

235   54.   The method of claim 48 wherein said decoding procedure comprises a

236   code sequence detection procedure to decode a trellis code, or convolutional code.

237

238   55.   The method of claim 54 wherein said code sequence detection procedure

239   employs a metric belonging to a group consisting of: Euclidean metric, weighted Euclidean

240   metric, and Hamming metric.

241

242   56.   The method of claim 48 wherein said decoding procedure reduces

243   deleterious effects of interference from undesired transmitters.

244

245   57.   The method of claim 35 further comprising the step of:

246   sending a retransmission request when received symbols are

247 determined to include errors.

248

249   58.   The method of claim 35 wherein said channel comprises a wireless

250 channel and said plurality of channel outputs are coupled to a plurality of corresponding

251 receiver antenna elements.

252

253   59.   The method of claim 35 wherein said plurality of receiver antenna

254 elements are co-located.

255

256   60.   The method of claim 35 wherein said plurality of receiver antenna

257 elements are at disparate locations.

258

259   61.   In a digital communication system, a method for preparing a sequence of

260 symbols for transmission via a plurality of inputs to a channel, said method comprising the

261 steps of:

262   selecting a weighting vector for optimal transmission;

263   applying a transmitter substantially orthogonalizing procedure to

264 said sequence of symbols to develop a time domain symbol sequence; and

265   multiplying at least one symbol of said time domain symbol

266 sequence by said weighting vector to develop a result vector, elements of said result vector

267 corresponding to symbols to be transmitted via individual ones of said plurality of channel

268 inputs.

269

270   62.   The method of claim 61 wherein said weighting vector comprises an

271 element indicating delay to be applied for a particular one of said plurality of channel inputs.

272

273   63.   The method of claim 61 wherein said weighting vector is optimized to

274 reduce interference to unintended receivers.

275

276 64.   The method of claim 61 wherein said weighting vector is chosen based
277 upon characterization of a desired signal subspace.

278

279 65.   The method of claim 64 wherein said weighting vector is chosen further
280 based upon characterization of an undesired signal subspace.

281

282 66.   The method of claim 65 wherein said characterizations of said desired
283 signal subspace and said undesired signal subspace are averaged over at least one of time and
284 frequency.

285

286 67.   The method of claim 61 wherein said channel comprises a wireless
287 channel and said plurality of channel inputs are associated with a plurality of transmitter
288 antenna elements.
289
290
291

292　　　　　　　　68.　　In a digital communication system, a method for processing a plurality

293　of symbols received via a plurality of outputs of a channel, said method comprising the steps

294　of:

295　　　　　　　　　　　　selecting a weighting vector for optimal reception;

296　　　　　　　　　　　　multiplying an input vector whose elements correspond to

297　symbols received substantially simultaneously via a selected one of said plurality of channel

298　outputs by said weighting vector to obtain a time domain symbol corresponding to a particular

299　input bin of a receiver substantially orthogonalizing procedure;

300　　　　　　　　　　　　repeating said multiplying step for successive received symbols to

301　obtain time domain symbols corresponding to successive input bins of said receiver

302　substantially orthogonalizing procedure; and

303　　　　　　　　　　　　applying said receiver substantially orthogonalizing procedure to

304　said obtained time domain symbols.

305

306　　　　　　　　69.　　The method of claim 68 wherein said weighting vector comprises an

307　element indicating delay to be applied for a particular one of said plurality of channel outputs.

308

309　　　　　　　　70.　　The method of claim 68 wherein said weighting vector is optimized to

310　reduce deleterious effects of interference from unintended transmitters.

311

312　　　　　　　　71.　　The method of claim 68 wherein said weighting vector is chosen based

313　upon characterization of a desired signal subspace.

314

315　　　　　　　　72.　　The method of claim 71 wherein said weighting vector is chosen further

316　based upon characterization of an undesired signal subspace.

317

318　　　　　　　　73.　　The method of claim 72 wherein said characerizations of said desired

319　signal subspace and said undesired signal subspace are averaged over at least one of frequency

320　and time.

321

322   74.   The method of claim 71 wherein said channel comprises a wireless

323 channel and said plurality of channel outputs are associated with a plurality of corresponding

324 receiver antenna elements.

325

326   75.   In a digital communication system, a method of preparing symbols for

327 transmission via a plurality of inputs of a channel, said method comprising the steps of:

328   directing symbols to input bins of a transmitter substantially

329 orthogonalizing procedure so that each input bin has an allocated symbol;

330   for each particular input bin, spatially processing said symbol

331 allocated to said particular input bin to develop a spatially processed symbol vector, each

332 element of said spatially processed symbol vector being assigned to one of said channel

333 inputs;

334   applying said transmitter substantially orthogonalizing procedure

335 for a particular channel input, inputs to said substantially orthogonalizing procedure being for

336 each input bin, a symbol of said processed symbol vector for said input bin corresponding to

337 said particular channel input; and

338   repeating said applying step for each of said plurality of channel

339 inputs.

340

341   76.   The method of claim 75 further comprising the step of:

342   applying a cyclic prefix processing procedure to outputs of said

343 substantially orthogonalizing procedure independently for each particular channel input.

344

345   77.   The method of claim 75 wherein said transmitter substantially

346 orthogonalizing procedure is optimized to reduce interference to unintended receivers.

347

348   78.   The method of claim 75 wherein said processing step comprises:

349   multiplying said symbol allocated to said particular input bin by a

350 beneficial weighting vector to obtain said spatially processed symbol vector.

351

352   79.   The method of claim 78 wherein said beneficial weighting vector is an

353   input singular vector of a matrix storing values indicative of said channel, said channel

354   coupling said plurality of channel inputs and one or more channel outputs.

355

356   80.   The method of claim 78 wherein said beneficial weighting vector is

357   chosen to select a beneficial spatial direction for transmission.

358

359   81.   The method of claim 80 wherein said beneficial weighting vector is

360   chosen to reduce interference to unintended receivers.

361

362   82.   The method of claim 81 wherein said beneficial weighting vector is

363   chosen based upon characterization of a desired signal subspace

364

365   83.   The method of claim 82 wherein said beneficial weighting vector is

366   chosen further based upon characterization of an undesired signal subspace.

367

368   84.   The method of claim 83 wherein said characterizations of said desired

369   signal subspace and said undesired signal subspace are averaged over at least one of time and

370   frequency.

371

372   85.   The method of claim 75 wherein said channel comprises a wireless

373   channel and said plurality of channel inputs are associated with a corresponding plurality of

374   transmitter antenna elements.

375

376   86.   In a digital communication system, a method for processing symbols

377   received by a plurality of outputs of a channel comprising the step of:

378   applying a receiver substantially orthogonalizing procedure to symbols received

379   via a particular one of said channel outputs;

380   repeating said applying step for each of said channel outputs to develop a result

381   vector for each of a plurality of output bins of said receiver substantially orthogonalizing

382   procedure, said result vector including a result symbol for each of said channel outputs; and

383   for each particular output bin of said receiver substantially orthogonalizing

384   procedure, spatially processing said result vector for said particular output bin to develop a

385   spatially processed result symbol for said particular output bin.

386

387   87.   The method of claim 86 further comprising the step of:

388   prior to said applying step, applying a cyclic prefix removal procedure to

389   symbols independently for each of said channel outputs.

390

391   88.   The method of claim 86 wherein said substantially orthogonalizing

392   procedure is optimized to reduce deleterious effects of interference from unintended

393   transmitters.

394

395   89.   The method of claim 86 wherein said spatially processing step comprises

396   multiplying a beneficial weighting vector by said result vector to obtain said spatially

397   processed result symbol.

398

399   90.   The method of claim 88 wherein said beneficial weighting vector is an

400   input singular vector of a matrix storing values indicative of characteristics of said channel,

401   said channel coupling one or more chanel inputs and said plurality of channel outputs.

402

403   91.   The method of claim 88 wherein said beneficial weighting vector is

404   chosen to select a particular spatial direction for reception.

405

406   92.   The method of claim 91 wherein said beneficial weighting vector is

407   chosen to minimize deleterious effects of interference from unintended transmitters.

408

409   93.   The method of claim 91 wherein said beneficial weighting vector is

410   chosen based upon characterization of a desired signal subspace.

411

412   94.   The method of claim 93 wherein said beneficial weighting vector is

413   chosen based upon characterization of an undesired signal subspace.

414

415   95. The method of claim 94 wherein said characterizations of said desired

416 signal subspace and said undesired signal subspace are averaged over at least one of time and

417 frequency.

418

419   96. The method of claim 86 wherein said channel comprises a wireless

420 channel and said plurality of channel outputs are associated with a corresponding plurality of

421 channel outputs.

422

423   97. In a digital communication system including a communication channel

424 having one or more inputs and at least one or more outputs, a method for determining

425 characteristics of said channel based on signals received by said one or more outputs,

426 comprising the steps of:

427   a) receiving via said one or more channel outputs, at least ν training symbols

428 transmitted via a particular spatial direction of said channel, ν being an extent in symbol

429 periods of a duration of significant terms of an impulse response of a channel; and

430   b) applying a substantially orthogonalizing procedure to said received at least

431 ν training symbols to obtain a time domain response for said spatial direction; and

432   c) applying an inverse of said substantially orthogonalizing procedure to a zero-

433 padded version of said time domain response to obtain a frequency response for said particular

434 spatial direction.

435

436   98. The method of claim 97 wherein said substantially orthogonalizing

437 procedure comprises an inverse Fast Fourier Transform and said inverse of said substantially

438 orthogonalizing procedure comprises a Fast Fourier Transform.

439

440   99. The method of claim 98 wherein said a) step comprises receiving exactly

441 ν training symbols.

442

443   100. The method of claim 97 further comprising the step of repeating said a),

444 b), c), and d) steps for a plurality of spatial directions.

101.   The method of claim 99 wherein each of said plurality of spatial directions corresponds to transmission through one of said plurality of channel inputs exclusively.

102.   The method of claim 98 wherein said v training symbols belong to a burst of N symbols and said characteristics are determined for said burst.

103.   The method of claim 102 further comprising the steps of repeating said a), b), c), and d) steps for successive bursts.

104.   The method of claim 103 further comprising the step of after, said b) step, smoothing said time-domain response over successive bursts.

105.   The method of claim 104 wherein said smoothing step comprises Kalman filtering.

106.   The method of claim 104 wherein said smoothing step comprises Wiener filtering.

107.   The method of claim 97 wherein said communication channel comprises known and unknown components, wherein said effects of said known components are removed by deconvolution, and characteristics of said unknown components are determined by said a), b), c), and d) steps, thereby reducing .

108.   In a digital communication system including a communication channel having one or more inputs and one or more outputs, a method for determining characteristics of said channel based on signals received via one or more channel outputs, comprising the steps of:

receiving training symbols via said channel outputs; and

475   computing characteristics of said channel based on said received

476   training symbols and assumptions that an impulse response of said channel is substantially

477   time-limited and that variation of said impulse response over time is continuous.

478

479   109.   In a digital communication system, a method for communicating over a

480   channel having at least one input and at least one output, and having a plurality of either inputs

481   or outputs, said method comprising the steps of:

482   dividing said channel into a plurality of subchannels, each

483   subchannel corresponding to a combination of spatial direction and an input bin of a

484   substantially orthogonalizing procedure; and

485   communicating symbols over one or more of said plurality of

486   subchannels.

487

488   110.   In a digital communication system, a method for preparing a sequence of

489   symbols for transmission via a plurality of inputs of a channel, comprising the steps of:

490   a) inputting said symbols of said sequence into a plurality of

491   input corresponding to a plurality of subchannels of said channel, each subchannel

492   corresponding to an input bin of a transmitter substantially orthogonalizing procedure and a

493   channel input; and

494   b) applying, independently for each said channel input, said

495   transmitter substantially orthogonalizing procedure to said symbols assigned to each said

496   channel input.

497

498   111.   A method of processing a sequence of symbols received via a plurality of

499   outputs of a channel, said method comprising the steps of:

500   a) applying a substantially orthogonalizing procedure to said

501   sequence of symbols, said procedure being applied independently for each of said plurality of

502   channel outputs, each output symbol of said substantially orthogonalizing procedure

503   corresponding to a subchannel identified by a combination of a particular output bin and a

504   particular one of said channel outputs; and

505   b) processing symbols in said subchannels.

506

507   112.   In a digital communication system, apparatus for communicating

508 comprising:

509   a transmitter that transmits signals from one or more transmitter

510 antenna elements;

511   a receiver that receives said signals from via a plurality of

512 receiver antenna elements;

513   wherein separation of radiation patterns among either said

514   transmitter antenna elements or said receiver antenna elements is insufficient to

515   establish completely isolated spatial directions for communication; and wherein

516   at least one of said transmitter and said receiver comprises a

517 processor that processes said signals to increase isolation between spatial directions employed

518 for communication at a common frequency.

519

520   113.   The apparatus of claim 112 wherein a channel coupling said plurality of

521 transmitter antenna elements and receiver antenna elements at said common frequency is

522 characterized by a spatial channel matrix having a rank greater than one.

523

524   114.   In a digital communication system, apparatus for communicating

525 comprising:

526   a transmitter transmitting signals from one or more transmitter

527 antenna elements;

528   a receiver receiving said signals via a plurality of receiver

529 antenna elements;

530   wherein separation of radiation patterns among either said

531   transmitter antenna elements or said receiver antenna elements is insufficient to

532   establish completely isolated spatial directions for communication; and wherein

533   at least one of said transmitter and said receiver comprises a

534 processor that processes said signals to increase isolation between subchannels, each

535 subchannel associated with a spatial direction and a bin of a substantially orthogonalizing

536 procedure.

537

538   115.   The apparatus of claim 114 wherein said substantially orthogonalizing

539 procedure belongs to a group including: an inverse Fast Fourier Transform, a Fast Fourier

540 Transform, a Hilbert transform, a wavelet transform, and processing through a set of bandpass

541 filter/frequency upconverter pairs operating at spaced apart frequencies..

542

543   116.   In a digital communication system, apparatus for preparing a sequence of

544 symbols for transmission via a plurality of inputs of a channel:

545   a plurality of parallel subchannel inputs receiving said symbols, said parallel

546 subchannel inputs corresponding to a plurality of subchannels, each subchannel corresponding

547 to an input bin of a transmitter substantially orthogonalizing procedure and a spatial direction;

548   a spatial processor that, for each input bin, spatially processor symbols received

549 by said subchannel inputs corresponding to said input bin, to develop a spatially processed

550 symbol to assign to each combination of channel input and input bin of said transmitter

551 substantially orthogonalizing procedure; and

552   a substantially orthogonal procedure processor system that applies,

553 independently for each said channel input, said transmitter substantially orthogonalizing

554 procedure to said spatially processed symbols assigned to each said channel input.

555

556   117.   The apparatus of claim 116 wherein said spatial processor has the effect

557 of making spatial directions of said subchannels into a set of orthogonal spatial dimensions.

558

559   118.   The apparatus of claim 116 wherein said transmitter substantially

560 orthogonalizing procedure belongs to one of a group consisting of an inverse Fast Fourier

561 Transform, a Fast Fourier Transform, a discrete cosine transform, a Hilbert transform, a

562 wavelet transform, and processing through a plurality of bandpass filter/frequency converter

563 pairs centered at spaced apart frequencies.

564

565   119.   The apparatus of claim 116 further comprising: a cyclic prefix processor

566 that applies a cyclic prefix processing procedure to a result of said substantially

567 orthogonalizing procedure independently for each channel input.

568

569   120.   The apparatus of claim 116 wherein said transmitter substantially
570 orthogonalizing procedure is optimized to reduce interference to unintended receivers.

571

572   121.   The apparatus of claim 116 wherein said spatial processor comprises, for
573 each particular input bin, a weight multiplier that multiplies a vector comprising symbols
574 allocated to subchannels corresponding to said input bin by a beneficial weighting matrix,
575 elements of a result vector of said weight multiplier corresponding to different channel inputs
576 of said plurality of channel inputs.

577

578   122.   The apparatus of claim 121 wherein said beneficial weighting matrix
579 comprises an input singular matrix of a matrix containing values representing characteristics of
580 said channel, said channel coupling said plurality of channel inputs to one or more channel
581 outputs.

582

583   123.   The apparatus of claim 121 wherein said beneficial weighting matrix is
584 obtained from a matrix containing values representing characteristics of a channel coupling
585 said plurality of channel inputs to one or more channel outputs.

586

587   124.   The apparatus of claim 121 wherein said beneficial weighting matrix is
588 chosen to reduce interference to unintended receivers.

589

590   125.   The apparatus of claim 124 wherein said beneficial weighting matrix is
591 chosen based upon characterization of a desired signal subspace.

592

593   126.   The apparatus of claim 125 wherein said beneficial weighting matrix is
594 chosen further based upon characterization of an undesired signal subspace.

595

596   127.   The apparatus of claim 126 wherein characterizations of said desired
597 signal subspace and said undesired signal subspace are averaged over at least one of time and
598 frequency.

599

600   128.   The apparatus of claim 116 wherein said spatial processor operates so as

601 to reduce interference radiated to unintended receivers.

602

603   129.   The apparatus of claim 116 wherein said spatial processor, allocates

604 symbols to each combination of channel input and input bin so that there is a one-to-one

605 mapping between spatial direction of a particular subchannel to which a particular symbol has

606 been allocated and channel input to which said particular symbol is allocated.

607

608   130.   The apparatus of claim 116 further comprising a coder that applies a

609 coding procedure to said symbols prior to processing by said spatial processor.

610

611   131.   The apparatus of claim 130 wherein said coding procedure is applied

612 independently for each of said subchannels.

613

614   132.   The apparatus of claim 130 wherein said coding procedure is applied

615 independently for each group of subchannels corresponding to an input bin of said substantially

616 orthogonalizing procedure.

617

618   133.   The apparatus of claim 130 wherein said coding procedure is applied

619 independently for each group of subchannels corresponding to a particular spatial direction.

620

621   134.   The apparatus of claim 130 wherein said coding procedure is applied

622 integrally across all of said subchannels.

623

624   135.   The apparatus of claim 130 wherein said coding procedure belongs to a

625 group consisting of: convolutional coding, Reed-Solomon coding, CRC coding, block coding,

626 trellis coding, turbo coding, and interleaving.

627

628   136.   The apparatus of claim 130 wherein said coding procedure comprises a

629 trellis coding procedure.

137. The apparatus of claim 136 wherein a code design of said trellis coding procedure is based on one of: improved bit error performance in interference channels, a periodic product distance metric, exhaustive code polynomial search for favorable bit error rate polynomial searches, combined weighting of product distance and Euclidean distance, product distance of multiple Euclidean distances over short code segments or over a multi-dimensional symbol, and sum of product distances over short code segments.

138. The apparatus of claim 136 wherein a code design of said trellis coding procedure is optimized for performance in a fading matrix channel.

139. The apparatus of claim 130 wherein said coding procedure comprises a one-dimensional trellis coding procedure followed by an interleaving procedure with sequential groups of symbols output by said trellis coding having their internal order maintained by said interleaving procedure.

140. The apparatus of claim 130 wherein said coding procedure comprises a multi-dimensional trellis coding procedure followed by an interleaving procedure with groups of one-dimensional symbols output simultaneously by said multi-dimensional trellis coding procedure having their internal order maintained by said interleaving procedure.

141. The apparatus of claim 130 wherein bit loading and power are allocated to each subchannel.

142. The apparatus of claim 116 further comprising an ARQ system that retransmits symbols via at least one of said spatial processor, and said substantially orthogonalizing procedure processor upon receipt of a notification that said symbols to be retransmitted have been incorrectly received.

659　　　143. The apparatus of claim 116 wherein said channel comprises a wireless

660　channel and said plurality of channel inputs are associated with a corresponding plurality of

661　transmitter antenna elements

662

663　　　144. The apparatus of claim 142 wherein said plurality of transmitter antenna

664　elements are co-located.

665

666　　　145. The apparatus of claim 144 wherein said plurality of transmitters are at

667　disparate locations.

668

669　　　146. Apparatus of processing a sequence of symbols received via a plurality

670　of outputs of a channel, said apparatus comprising:

671　　　a substantially orthogonalizing procedure processor system that applies a

672　receiver substantially orthogonalizing procedure to said sequence of symbols, said procedure

673　being applied independently for each of said plurality of channel outputs, each output symbol

674　of said substantially orthogonalizing procedure corresponding to a particular output bin and a

675　particular one of said channel outputs; and

676　　　a spatial processor that, for each output bin, spatially processes symbols

677　corresponding to said output bin to develop spatially processed symbols assigned to a plurality

678　of spatial directions, each combination of spatial direction and output bin specifying one of a

679　plurality of subchannels.

680

681　　　147. The apparatus of claim 146 wherein said spatial processor operates to

682　make said plurality of spatial directions into a set of orthogonal spatial dimensions.

683

684　　　148. The apparatus of claim 146 wherein said receiver substantially

685　orthogonalizing procedure belongs to one of a group consisting of an inverse Fast Fourier

686　Transform, a Fast Fourier Transform, a discrete cosine transform, a Hilbert transform, a

687　wavelet transform, and processing through a plurality of bandpass filter/frequency converter

688　pairs centered at spaced apart frequencies.

689

690   149.   The apparatus of claim 146 further comprising: a cyclic prefix processor

691   that applies a cyclic prefix removal procedure to said sequence of symbols independently for

692   each of said channel outputs.

693

694   150.   The apparatus of claim 146 wherein said receiver substantially

695   orthogonalizing procedure is optimized to reduce deleterious effects of interference from

696   undesired co-channel transmitters.

697

698   151.   The apparatus of claim 146 wherein said spatial processor comprises, for

699   each particular output bin, a weight multiplier that multiplies a vector comprising symbols of

700   said output bin by a beneficial weighting matrix, elements of a result vector of said multiplier

701   corresponding to different spatial directions.

702

703   152.   The apparatus of claim 151 wherein said beneficial weighting matrix

704   comprises an output singular vector of a matrix containing values representing characteristics

705   of said channel, said channel coupling one or more channel inputs to said plurality of channel

706   outputs.

707

708   153.   The apparatus of claim 151 wherein said beneficial weighting matrix is

709   chosen to minimize deleterious effects of interference from undesired transmitters.

710

711   154.   The apparatus of claim 151 wherein said beneficial weighting matrix is

712   chosen based upon characterization of a desired signal subspace.

713

714   155.   The apparatus of claim 154 wherein said beneficial weighting matrix is

715   chosen further based upon characterization of an undesired signal subspace.

716

717   156.   The apparatus of claim 155 wherein said characterizations of said desired

718   signal subspace and said undesired signal subspace are averaged over at least one of time and

719   frequency.

720

721 157. The apparatus of claim 151 wherein said beneficial weighting matrix is

722 obtained from a matrix containing values representing characteristics of said channel, said

723 channel coupling one or more channel inputs and said plurality of channel outputs.

724

725 158. The apparatus of claim 157 wherein said beneficial weighting matrix is

726 obtained by an MMSE procedure.

727

728 159. The apparatus of claim 146 further comprising: a decoder that applies a

729 decoding procedure to said spatially processed symbols.

730

731 160. The apparatus of claim 159 wherein said decoding procedure is applied

732 independently for each of said plurality of subchannels.

733

734 161. The apparatus of claim 159 wherein said decoding procedure is applied

735 independently for each group of subchannels corresponding to an output bin of said

736 substantially orthogonalizing procedure.

737

738 162. The apparatus of claim 159 wherein said decoding procedure is applied

739 independently for each group of subchannels corresponding to a spatial direction.

740

741 163. The apparatus of claim 159 wherein said decoding procedure is applied

742 integrally across all of said plurality of subchannels.

743

744 164. The apparatus of claim 159 wherein said decoding procedure belongs to

745 a group consisting of: Reed-Solomon decoding, CRC decoding, block decoding, and de-

746 interleaving.

747

748 165. The apparatus of claim 159 wherein said decoding procedure comprises a

749 code sequence detection procedure to decode a trellis code, or convolutional code.

750

751   166.   The apparatus of claim 165 wherein said code sequence detection

752   procedure employs a metric belonging to a group consisting of: Euclidean metric, weighted

753   Euclidean metric, and Hamming metric.

754

755   167.   The apparatus of claim 159 wherein said decoding procedure reduces

756   deleterious effects of interference from undesired transmitters.

757

758   168.   The apparatus of claim 146 further comprising:

759   a system that sends a retransmission request when received symbols are

760   determined to include errors.

761

762   169.   The apparatus of claim 170 wherein said channel comprises a wireless

763   channel and said plurality of channel outputs are coupled to a plurality of corresponding

764   receiver antenna elements.

765

766   171.   The apparatus of claim 170 wherein said plurality of receiver antenna

767   elements are co-located.

768

769   172.   The apparatus of claim 170 wherein said plurality of receiver antenna

770   elements are at disparate locations.

771

772   173.   In a digital communication system, apparatus for preparing a sequence of

773   symbols for transmission via a plurality of inputs to a channel, said apparatus comprising:

774   a substantially orthogonal procedure processor that applies a transmitter

775   substantially orthogonalizing procedure to said sequence of symbols to develop a time domain

776   symbol sequence; and

777   a weight multiplier that multiplies at least one symbol of said time domain

778   symbol sequence by a weighting vector selected for improved communication to develop a

779   result vector, elements of said result vector corresponding to symbols to be transmitted via

780   individual ones of said plurality of channel inputs.

781

782   174.   The apparatus of claim 173 wherein said weighting vector comprises an

783   element indicating delay to be applied for a particular one of said plurality of channel inputs.

784

785   175.   The apparatus of claim 174 wherein said weighting vector is optimized

786   to reduce interference to unintended receivers.

787

788   176.   The apparatus of claim 173 wherein said weighting vector is chosen

789   based upon characterization of a desired signal subspace.

790

791   177.   The apparatus of claim 176 wherein said weighting vector is chosen

792   further based upon characterization of an undesired signal subspace.

793

794   178.   The apparatus of claim 177 wherein said characterizations of said desired

795   signal subspace and said undesired signal subspace are averaged over at least one of time and

796   frequency.

797

798   179.   The apparatus of claim 173 wherein said channel comprises a wireless

799   channel and said plurality of channel inputs are associated with a

800   plurality of transmitter antenna elements.

801   ~~180.~~

802   180.   In a digital communication system, apparatus for processing a plurality

803   of symbols received via a plurality of outputs of a channel, said apparatus comprising:

804   a weight multiplier that performs a multiplication of an input vector whose

805   elements correspond to symbols received substantially simultaneously via a selected one of said

806   plurality of channel outputs by a weighting vector to obtain a time domain symbol

807   corresponding to a particular input bin of a receiver substantially orthogonalizing procedure

808   and that repeats said multiplication for successive received symbols to obtain time domain

809   symbols corresponding to successive input bins of said receiver substantially orthogonalizing

810   procedure; and

811   a substantial orthogonalizing procedure processor that applies said substantially

812   orthogonalizing procedure processor to said obtained time domain symbols.

813

814   181.   The apparatus of claim 180 wherein said weighting vector comprises an

815   element indicating delay to be applied for a particular one of said plurality of channel outputs.

816

817   182.   The apparatus of claim 180 wherein said weighting vector is optimized

818   to reduce deleterious effects of interference from unintended transmitters.

819

820   183.   The apparatus of claim 180 wherein said weighting vector is chosen

821   based upon characterization of a desired signal subspace.

822

823   184.   The apparatus of claim 183 wherein said weighting vector is chosen

824   further based upon characterization of an undesired signal subspace.

825

826   185.   The apparatus of claim 184 wherein said characterizations of said desired

827   signal subspace and said undesired signal subspace are averaged over at least one of frequency

828   and time.

829

830   186.   The apparatus of claim 180 wherein said channel comprises a wireless

831   channel and said plurality of channel outputs are associated with a plurality of corresponding

832   receiver antenna elements.

833

834   187.   In a digital communication system, apparatus for preparing symbols for

835   transmission via a plurality of inputs of a channel, said apparatus comprising:

836   a plurality of symbol inputs, each of said symbol inputs receiving a symbol

837   intended for a particular input bin of a transmitter substantially orthogonalizing procedure so

838   that each of a plurality of input bins of said transmitter substantially orthongonalizing

839   procedure has an allocated symbol;

840   a spatial processor that, for each particular input bin of said plurality of input

841   bins, spatially processes said symbol allocated to said particular input bin to develop a spatially

842   processed symbol vector, each element of said spatially processed symbol vector being

843   assigned to one of said channel inputs; and

844   a substantially orthogonalizing procedure processor that applies said

845 substantially orthogonalizing procedure for a particular channel input, inputs to said

846 substantially orthogonalizing procedure being for each input bin, a symbol of said processed

847 symbol vector for said input bin corresponding to said particular channel input, and that

848 applies said sustantially orthogonalizing procedure for each of said plurality of channel inputs.

849

850   188.   The apparatus of claim 187 further comprising:

851   a cyclic prefix processor that applies a cyclic prefix processing procedure to

852 outputs of said substantially orthogonalizing procedure independently for each particular

853 channel input.

854

855   189.   The apparatus of claim 187 wherein said substantially orthogonalizing

856 procedure is optimized to reduce interference to unintended receivers.

857

858   190.   The apparatus of claim 187 wherein said spatial processor comprises:

859   a weight multiplier that multiplies said symbol allocated to said particular input

860 bin by a beneficial weighting vector to obtain said spatially processed symbol vector.

861

862   191.   The apparatus of claim 190 wherein said beneficial weighting vector is

863 an input singular vector of a matrix storing values indicative of characteristics of said channel,

864 said channel coupling said plurality of channel inputs and one or more channel outputs.

865

866   192.   The apparatus of claim 190 wherein said beneficial weighting vector is

867 chosen to select a beneficial spatial direction for transmission.

868

869   193.   The apparatus of claim 191 wherein said beneficial weighting vector is

870 chosen to reduce interference to unintended receivers.

871

872   194.   The apparatus of claim 193 wherein said beneficial weighting vector is

873 chosen based upon characterization of a desired signal subspace

874

875   195.   The apparatus of claim 194 wherein said beneficial weighting vector is

876   chosen further based upon characterization of an undesired signal subspace.

877

878   196.   The apparatus of claim 195 wherein said characterizations of said desired

879   signal subspace and said undesired signal subspace are averaged over at least one of time and

880   frequency.

881

882   197.   The apparatus of claim 187 wherein said channel comprises a wireless

883   channel and said plurality of channel inputs are associated with a corresponding plurality of

884   transmitter antenna elements.

885

886   198.   In a digital communication system, apparatus for processing symbols

887   received by a plurality of outputs of a channel comprising:

888   a substantially orthogonalizing procedure processor that applies a receiver

889   substantially orthogonalizing procedure to symbols received via a particular one of said

890   channel outputs and that said applies said receiver substantially orthogonalizing procedure for

891   each of said channel outputs to develop a result vector for each of a plurality of output bins of

892   said substantially orthogonalizing procedure, said result vector including a result symbol for

893   each of said channel outputs; and

894   a spatial processor that, for each particular output bin of said substantially

895   orthogonalizing procedure, spatially processes said result vector for said particular output bin

896   to develop a spatially processed result symbol for said particular output bin.

897

898   199.   The apparatus of claim 198 further comprising: a cyclic prefix removal

899   processor that applies a cyclic prefix removal procedure to symbols independently for each of

900   said channel outputs.

901

902   200.   The apparatus of claim 198 wherein said substantially orthogonalizing

903   procedure is optimized to reduce deleterious effects of interference from unintended

904   transmitters.

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201. The apparatus of claim 198 wherein said spatially processor comprises a weight multiplier that multiplies a beneficial weighting vector by said result vector to obtain said spatially processed result symbol.

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202. The apparatus of claim 201 wherein said beneficial weighting vector is an input singular vector of a matrix storing values indicative of characteristics of said channel, said channel coupling one or more chanel inputs and said plurality of channel outputs.

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203. The apparatus of claim 201 wherein said beneficial weighting vector is chosen to select a particular spatial direction for reception.

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919

204. The apparatus of claim 203 wherein said beneficial weighting vector is chosen to minimize deleterious effects of interference from unintended transmitters.

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205. The apparatus of claim 204 wherein said beneficial weighting vector is chosen based upon characterization of a desired signal subspace.

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925

206. The apparatus of claim 205 wherein said beneficial weighting vector is chosen based upon characterization of an undesired signal subspace.

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207. The apparatus of claim 206 wherein said characterizations of said desired signal subspace and said undesired signal subspace are averaged over at least one of time and frequency.

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208. The apparatus of claim 198 wherein said channel comprises a wireless channel and said plurality of channel outputs are associated with a corresponding plurality of channel outputs.

934
935

209. In a digital communication system including a communication channel having one or more inputs and at least one or more outputs apparatus for determining

936 characteristics of said channel based on signals received by said one or more outputs,

937 comprising:

938   a receiver system receiving via said one or more channel outputs, at least

939 training symbols transmitted via a particular spatial direction of said channel,   being an extent

940 in symbol periods of a duration of significant terms of an impulse response of a channel;

941   a substantially orthogonalizing procedure processor that applies a substantially

942 orthogonalizing procedure processor to said received at least   training symbols to obtain a

943 time domain response for said particular spatial direction; and

944   an inverse substantially orthogonalizing procedure processor that applies an

945 inverse of said substantially orthogonalizing procedure to a zero-padded version of said time

946 domain response to obtain a frequency response for said particular spatial direction.

947

948   210.   The apparatus of claim 209 wherein said substantially orthogonalizing

949 procedure comprises an inverse Fast Fourier Transform and said inverse of said substantially

950 orthogonalizing procedure comprises a Fast Fourier Transform.

951

952   211.   The apparatus of claim 209 wherein said receiver system receives exactly

953 training symbols.

954

955   212.   The apparatus of claim 209 wherein said receiver system, said

956 substantially orthogonalizing procedure processor and said inverse substantially

957 orthogonalizing procedure process operate repeatedly for a plurality of spatial directions.

958

959   213.   The apparatus of claim 209 wherein each of said plurality of spatial

960 directions corresponds to transmission through one of said plurality of channel inputs

961 exclusively.

962

963   214.   The apparatus of claim 209 wherein said   training symbols belong to a

964 burst of N symbols and said characteristics are determined for said burst.

965

966
967
968   215.   The apparatus of claim 214 said receiver system, said substantially
orthogonalizing procedure processor and said inverse substantially orthogonalizing procedure
process operate repeatedly for a plurality of bursts.

969

970   216.   The apparatus of claim 215 further comprising:

971   means for smoothing said time-domain response over successive bursts.

972

973   217.   The apparatus of claim 216 wherein said smoothing means comprises:

974   means for Kalman filtering said time-domain response over successive bursts.

975

976   218.   The apparatus of claim 217 wherein said smoothing means comprises

977   means for Wiener filtering said time-domain response over successive bursts.

978

979   219.   The apparatus of claim 209 wherein said communication channel

980   comprises known and unknown components, wherein said effects of said known components

981   are removed by deconvolution, and characteristics of said unknown components are

982   determined by said a), b), c), and d) steps, thereby reducing .

983

984   220.   In a digital communication system including a communication channel

985   having one or more inputs and one or more outputs, apparatus for determining characteristics

986   of said channel based on signals received via one or more channel outputs, comprising:

987   a receiver that receives training symbols via said channel outputs; and

988   a processor that computes characteristics of said channel based on said received

989   training symbols and assumptions that an impulse response of said channel is substantially

990   time-limited and that variation of said impulse response over time is continuous.

991

992   221.   In a digital communication system, apparatus for communicating over a

993   channel having at least one input and at least one output, and having a plurality of either inputs

994   or outputs, said apparatus comprising:

995 means for dividing said channel into a plurality of subchannels, each subchannel

996 corresponding to a combination of spatial direction and an input bin of a substantially

997 orthogonalizing procedure; and

998 means for communicating symbols over one or more of said plurality of

999 subchannels.

1000

1001 222. In a digital communication system, apparatus for preparing a sequence of

1002 symbols for transmission via a plurality of inputs of a channel, said apparatus comprising:

1003 a plurality of parallel subchannel inputs that receive said sequence of symbols,

1004 said subchannel inputs corresponding to a plurality of subchannels, each subchannel

1005 corresponding to an input bin of a transmitter substantially orthogonalizing procedure and a

1006 channel input; and

1007 a substantially orthogonalizing procedure processor that applies, independently

1008 for each said channel input, said transmitter substantially orthogonalizing procedure to said

1009 symbols assigned to each said channel input.

1010

1011 223. Apparatus for processing a sequence of symbols received via a plurality

1012 of outputs of a channel, said apparatus comprising the steps of:

1013 a substantially orthogonalizing procedure processor that applies a receiver

1014 substantially orthogonalizing procedure to said sequence of symbols, said procedure being

1015 applied independently for each of said plurality of channel outputs, each output symbol of said

1016 receiver substantially orthogonalizing procedure corresponding to a subchannel identified by a

1017 combination of a particular output bin and a particular one of said channel outputs; and

1018 a processor that processes symbols in said subchannels.